IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

| | |
|---|---|
| Applicant(s): | Ian John Patrick James |
| Serial No.: | 09/852,926 |
| Filed: | May 10, 2001 |
| For: | FAULT MONITORING SYSTEM |
| Examiner: | Anne L. Damiano |
| Art Unit: | 2114 |
| Attorney Docket: | 360.7418USU |
| Customer No.: | 27623 |

OIPE JCSS
DEC 0 1 2004
PATENT & TRADEMARK OFFICE

COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, VA 22313-1450

**REQUEST FOR ENTRY OF PRIORITY CLAIM AND SUBMISSION OF PRIORITY DOCUMENT**

Dear Sir:

Applicant hereby requests that a priority claim under 35 U.S.C. §119 be entered in the above-identified application as follows: Great Britain Application No. 0011251.6 filed on May 11, 2000, for the above noted application.

We are also enclosing a certified copy of the priority document, Great Britain Application No. 0011251.6 filed on May 11, 2000, for filing in the above noted application.

It is respectfully requested that this application be passed to allowance.

Respectfully submitted,

Date: November 29, 2004

Paul D. Greeley, Esq.
Ohlandt, Greeley, Ruggiero & Perle, L.L.P.
Attorney for Applicants
Registration No. 31,019
One Landmark Square, 10th Floor
Stamford, Connecticut 06901-2682
Telephone: (203) 327-4500
Telefax: (203) 327-6401

The Patent Office

INVESTOR IN PEOPLE

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

# CERTIFIED COPY OF PRIORITY DOCUMENT

t  undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) t  Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the or  oller-General, hereby certify that annexed hereto is a true copy of the documents as ig  ly filed in connection with the patent application identified therein.

acc  lance with the Patents (Companies Re-registration) Rules 1982, if a company named this  tificate and any accompanying documents has re-registered under the Companies Act 80  h the same name as that with which it was registered immediately before re-istr  n save for the substitution as, or inclusion as, the last part of the name of the words ublic  ited company" or their equivalents in Welsh, references to the name of the company this  ificate and any accompanying documents shall be treated as references to the name h w  it is so re-registered.

ccor  e with the rules, the words "public limited company" may be replaced by p.l.c., , P.L.  or PLC.

regist  n under the Companies Act does not constitute a new legal entity but merely jects t  ompany to certain additional company law rules.

Signed

Dated 11 MAY 2001

BEST AVAILABLE COPY

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form

Description 11

Claim(s)

Abstract

Drawing(s) 6+6

10. If you are also filing any of the following, state how many against each item.

Priority documents

Translations of priority documents



Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*

Request for preliminary examination and search *(Patents Form 9/77)*

Request for substantive examination *(Patents Form 10/77)*

Any other documents *(please specify)*

11. I/We request the grant of a patent on the basis of this application.

Signature

Date 10 MAY 2000

12. Name and daytime telephone number of person to contact in the United Kingdom

Sean J. Hackett 0121 643 5881

**Warning**

*After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.*

Patents Form 1/77

Patents Act 1977
(Rule 16)

THE PATENT OFFICE
11 MAY 2000
NEWPORT

The Patent Office

1/77

11MAY00 E535582 D00355
P01/7700 0.00-0011251.6

The Patent Office

Cardiff Road
Newport
Gwent NP10 8QQ

# Request for grant of a patent

*(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)*

11 MAY 2000

1. Your reference — F070200PGB

2. Patent application number *(The Patent Office will fill in this part)* — 0011251.6

3. Full name, address, and postcode of the or of each applicant *(underline all surnames)* — Lucas Industries Limited, 46 Park Street, London W1Y 4DJ

   Patents ADP number *(if you know it)* — 576694003

   If the applicant is a corporate body, give the country/state of its incorporation — United Kingdom

BEST AVAILABLE COPY

4. Title of the invention — FAULT MONITORING SYSTEM

5. Name of your agent *(if you have one)* — Marks & Clerk

   "Address for Service" in the United Kingdom to which all correspondence should be sent *(including the postcode)* — Alpha Tower, Suffolk Street Queensway, Birmingham B1 1TT

   Patents ADP number *(if you know it)* — 18002

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

| Country | Priority application number *(if you know it)* | Date of filing *(day / month / year)* |
|---|---|---|
| | | |

7. If this application is divided or otherwise derived from an earlier UK application give the number and filing date of the earlier application

| Number of earlier application | Date of filing *(day / month / year)* |
|---|---|
| | |

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
   *a) any applicant named in part 3 is not an inventor, or*
   *b) there is an inventor who is not named as applicant, or*
   *c) any named applicant is a corporate body.*
   *See note (d))*

BEST AVAILABLE COPY

# Fault Monitoring System

This invention relates to a fault monitoring system for providing an indication of the presence of faults detected in, for example, a system for monitoring operating parameters within an aircraft.

In a known fault monitoring system, in order to discriminate between intermittent and persistent or "hard" faults, an operating parameter is checked for the presence of a fault during successive sampling periods which may be, for example, at one second intervals. An integrator is provided which counts or ramps upwards towards a fault confirmation threshold every time a fault is sensed and counts or ramps downwards between sampling periods in which no fault is sensed. The integrator has an integration ratio which is such that for every upward count consequent on a fault detection, there are N fault free sampling periods for an equivalent downward count. For example, if a system has a fault confirmation threshold of 30, a sample rate of one second and an integration ratio of 1:50, a fault will be confirmed as a hard fault after 30 samples, i.e. 30 seconds. That is to say, the hard fault is confirmed once the integrator reaches a preset count or threshold, in this case 30. The system engineer can then investigate the fault in the knowledge that the fault has been declared "hard" and should therefore be reproducible/ visible during fault isolation. Clearly, the fastest descent possible from the maximum count of 30 to zero in the case where successive samples are fault-free following confirmation of a "hard" fault, will take 30x50 seconds.

If the fault is intermittent, in which some sampled periods will indicate the presence of a fault while others will not, the integrator will count up and down according to the ratio of fault to non-fault sampling periods having regard to the integration ratio. Hence, an intermittent fault with a ratio of

greater than one fault in 50 samples will eventually be confirmed as a hard fault. Depending of the degree of intermittency, the integrator may reach and move away from the preset count or threshold periodically. The system is therefore capable of registering such events as recurrent intermittent faults. Whether it does so, or registers them as confirmed hard faults depends on whether the fault is steady or periodically random. For example, in the case where the degree of intermittency is low, but not so low relative to the integration ratio that the integrator never reaches the preset count, the preset count threshold may only be reached after a long period of time. When reached, the system will indicate the presence of a confirmed hard fault even though the fault is essentially a very intermittent one. For an intermittent fault occurring less frequently than the integrator ratio, the integrator will never reach the preset count and no hard fault or intermittent fault will be confirmed by the system, ensuring that those faults that have no effect on the functionality are ignored.

Currently, the fault detection system may determine whether a fault is intermittent or persistent (hard) by counting the number of times that the integration count reaches a threshold value. If a count reaches a threshold only once then it is recorded as a hard fault and is flagged as such by the detection system. If the count reaches the threshold more than once then the fault is flagged as intermittent. Such a system has the disadvantage that the type of intermittency is not recorded. Also intermittent faults which take a considerable time to integrate to the threshold value may never reach the threshold a second time in order to be classified as intermittent and are therefore flagged by the system as hard. If the fault is classified as hard, the system engineer will expect the fault to be visible during fault isolation and as a consequence may reject the wrong component if unable to confirm a continuity fault. The problem is particularly seen in the case of thermocouple temperature sensors. These devices generate signals of the order of only a

few mV and are therefore particularly prone to intermittent connection problems. With the increased functionality and complexity of modern electronic controllers comes an increase in the number of nuisance messages generated by low intermittency faults. These faults often have no system effect but result in the rejection of the electronic controller due to poor troubleshooting.

One solution to this could be to 'mask' the problem by increasing the thresholds at which an intermittent fault is registered as 'hard'. In the integrator system described previously, this could be done by increasing the integrator threshold from 30 to, say, 40. Any change to the fault integration system must be made in the knowledge that the system is tolerant to the fault for the period in which the fault condition is active prior to detection. This is often a very difficult analysis to complete.

It is an aim of the present invention to provide a fault monitoring system that can provide the systems engineer with a more robust system for determining and distinguishing between intermittent and hard faults. In particular, it is an aim of the present invention to provide the engineer with information about the nature of the intermittent fault which will permit him to make a more informed decision as to what, if any, action is required in response thereto. It is also an aim of the present invention to make this information available to the systems engineer prior to fault annunciation by the control system. The engineer will therefore have a basis for monitoring the 'general health' of the system being monitored on an ongoing real-time basis.

According to the present invention, there is provided a fault monitoring system comprising a fault detection mechanism to determine the status of a parameter to be monitored, an integrator for counting in one

direction when a fault in the measurement system is detected and for counting in an opposite direction in the absence of fault detection, a threshold detector for generating a hard fault indication when the integrator count reaches a threshold value, and an integrator count monitor for generating information indicative of the state of the integrator count when below the threshold value thereby to provide an indication of the progression of the fault.

The counting in the one direction may be at a rate equal to or higher than the rate of counting in the opposite direction.

In embodiments of the present invention, it is possible to monitor the progress of the sensed faults prior to the generation of a hard or confirmed fault message. Consequently, embodiments of the invention have the advantage that they provide an indication of the state of health of the system being monitored. Embodiments provide for the monitoring of trends in the fault counts of intermittent faults enabling prediction of specific failure conditions. More particularly, by correlating the progression of the sensed faults with system operating parameters, it is possible to relate the sensed fault to possible causes. This enables provision of a fault diagnostic capability. For example, if the fault occurs only when vibration levels are high, which may be the case during take off of an aircraft, the fault indication could be indicative of an impending connector failure. Steps may be taken to remedy the fault before actual failure of the component. Other fault indications may arise which indicate conditions not likely to result in a degrading performance or system failure in which case the system engineer, armed with more information, can decide whether remedial action is appropriate.

In a preferred embodiment of the present invention, the integrator count monitor generates an indication of the ratio between the count in one direction and the count in the opposite direction for providing the information as to the progression of the sensed fault towards or away from a hard or intermittent fault condition. In this case, the ratio may be averaged over a predetermined period of time or for the duration of a specified system operating condition. For example, if the ratio of the integrator count in the one direction to the count in the opposite direction is only high during specific operating conditions of an aircraft, it is possible that the fault is indicative of a failure mechanism made apparent due to high levels of vibration at these times. The system may thus be provided with means for correlating the information generated by the integrator count monitor with system operating conditions and so provide fault status or diagnostic information in response to the correlation.

In an alternative embodiment to reduce the requirement for data transfer to a health monitoring system, the integrator count monitor may generate further indication dependent on the integrator count relative to a sub-threshold value, which is set below the nominal threshold value. In this case, the information indicative of the state of the integrator count may be any one of: the frequency with which the integrator count exceeds the sub-threshold value; the total time this sub-threshold value is exceeded; the maximum continuous period the integrator count exceeds the sub-threshold. As with the first embodiment, the information indicative of the state of the integrator may be correlated with operating phases of the system and the system may be operative to generate appropriate system health messages.

The invention will now be further described by way of example with reference to the accompanying drawings in which:

Figure 1 is a flow chart with reference to which a prior art fault monitoring system will be described;

Figure 2a is a graph illustrating the integrator count for two different fault scenarios in the prior art system of Figure 1;

Figures 2b to 2e show, for illustrative purposes, four different fault scenarios according to a different integrator count regime from that of figure 2a;

Figure 3 is a flow chart with reference to which a first embodiment of the invention will be described;

Figure 4 is a flow chart with reference to which a second embodiment of the present invention will be described; and

Figure 5 is a graph showing the progression of integrator counts in the embodiment of Figure 4.

A prior art fault monitoring system comprises an integrator which counts upwardly towards a threshold value (see Z of Figure 2a) each time a fault is detected during a sampling period. The prior art fault monitoring system is initialised with the integrator value at zero as indicated in step 1 of Figure 1 and shown as point A in Figure 2a. The system reads at step 2 a signal received from a transducer providing a measure of the input parameter being monitored. At step 3, the received signal is validated using one or more fault detection methods. Range checks, cross-checks and model checks are often used in combination to ensure high integrity fault detection. Step 4 determines whether the received signal is indicative of the existence of a fault. If a fault is identified at step 4, a check is made at step 5 to see

whether or not the integrator count is greater than or equal to the threshold Z. If the integrator count is greater than or equal to the threshold value Z, then an affirmative indication Y restarts the signal check routine. In this way, the fault count is prevented from exceeding the threshold. If the integrator count is less than Z, the integrator count is upwardly incremented at step 6 by a value X equivalent to the up-count of the integrator. At step 7, the upwardly incremented count value is checked again whether it is greater than or equal to the threshold value Z. An affirmative result is confirmed as a hard fault at step 8 otherwise the incremented integrated count value is stored and the routine restarted to check the presence of a fault in the next sample. In the next sample, it is possible that step 4 determines the absence of a fault, in which case the system is operative at step 9 to check whether the current indicator count value is greater than or equal to the down count value Y. If the integrator count value is currently not greater than or equal to the down count value Y, then in order to avoid a negative count, the system routine is restarted in readiness for the next signal sample. On the other hand, if at step 9 the current integrator count value is determined as being greater than or equal to the down count Y, then the integrator count value is decremented by Y at step 10.

Figure 2a illustrates two possible count profiles for the system described with reference to Figure 1. In this system, the integrator has an integration ratio of 1:50 and a threshold value Z of 30. If the signal sampling is at the rate of one sample per second (see count profile i of Figure 2a), then the minimum time it takes the system to confirm a fault is 30 seconds, that is to say the time for the count to move from point A of Figure 2a to point B. The integration ratio of 1:50 means that there must be 50 no-fault samples to achieve an equivalent downward count. In this case, the minimum time for the integrator to return from the threshold value B to zero at point C of Figure 2a is 30x50 (i.e. twenty five minutes). In this example, the transducer

being monitored causes the integrator to meet the threshold value Z for a second time at point D. The fault monitoring system recognises the return of the integrator count value to the threshold value Z as an intermittent fault. The system therefore indicates the fault profile represented by the count profile i as a recurrent hard fault.

An alternative fault scenario is indicated by the count profile ii of Figure 2a. In this case, the fault occurs for considerably shorter periods, i.e. it is more intermittent, but the ratio between fault and non-fault samples relative to the integrator ratio is such that over a long period of time the threshold Z is reached as indicated at point E of Figure 2a. In this case, the system indicates the presence of a hard fault even though the fault is essentially a very intermittent one. The prior art fault monitoring system therefore suffers from the disadvantage that it is not possible to distinguish properly between hard faults, hard recurrent faults and periodic intermittent faults.

In Figures 2b to 2e, the integrator count is set for illustrative purposes so that there is an upward count of 5 for every fault sample and a downward count of 1 for every fault free sample. These figures illustrate four different fault scenarios respectively. In Figure 2b, a situation where a fault is permanent, i.e. 'hard', is indicated. In Figure 2c, a situation where the fault is periodically intermittent over the long term is indicated but the character of the fault is such that the threshold is not reached. In this case, the system does not indicate the presence of a fault. Figures 2d and 2e illustrate two different intermittent fault scenarios which prior art systems cannot distinguish between. Both intermittent fault scenarios are such that the threshold is reached and the system indicates the presence of a fault. However, in the case of Figure 2d, the nature of the fault is such that it is intermittent over the long term, resulting in a hard fault indication. In

contrast, the nature of the fault giving rise to the count profile illustrated in Figure 2e is such that it occurs persistently during particular engine operation phases only rather than consistently over the long term. This scenario is indicated as an intermittent fault.

The flow chart of Figure 3 illustrates an embodiment of the invention in which the fault monitoring system is provided with means for measuring the trend of the integrator count towards and away from the threshold value. The fault monitoring system of Figure 3 performs similar steps to those described with reference to Figure 1 except that in steps 11 and 12, an absolute fault and no fault count is initiated and incremented at steps 13 and 14 depending on whether or not a fault is determined at step 4. The ratio between the cumulative number of faults counted at step 13 to the cumulative number of non-faults counted at step 14 is calculated at step 15. It is therefore possible to record the trend in the ratio of the fault periods against the number of fault-free periods. This data trend is capable of indicating a worsening fault situation in which a hard fault would eventually be indicated by the system. The system may be operative for calculating the ratio of fault periods against non-fault periods over an entire operating sequence, for example an entire aircraft flight. In this case, the result would indicate the overall health of the parameter under review. A different type of indication such as a ratio of failures during a particular flight condition, such as take-off or descent may highlight transient effects such as vibration or temperature changes, which are more likely to be a factor influencing the generation of faults. The number of samples used to calculate the fault to non-fault ratio is a matter of design choice depending on the diagnostic objective and computing performance available.

An alternative embodiment is described with reference to Figure 4, with similar steps to those of Figures 1 and 3 and bearing similar reference numerals. In this case, only the steps leading from decision box 4 are shown in Figure 4 to highlight the differences between this method and that illustrated by Figure 3. In this alternative embodiment, instead of determining the ratio or gradient between upward and downward counts, the system is operative for providing an indication of the degree to which the integrator count value exceeds a lower integrator threshold or sub-threshold W (see Figure 5). In this embodiment, if no fault is sensed at decision box 4, it is determined at step 16 whether the integrator count is greater than the sub-threshold value W. If the result in step 16 is affirmative, a record of the time that the integrator count remains continuously above the threshold W is increased at step 17. At step 18, a count representing the total time the count is above threshold W is increased. In the event that the integrator count is determined at step 16 to have fallen below the sub-threshold W, the count is reset to zero at step 19. The system then proceeds to check at step 9 whether the integrator count can be decremented at step 10 as previously described with reference to Figure 1.

In the event that a fault is confirmed at step 4, the system determines at step 5 whether the integrator count is greater than or equal to the fault confirmation threshold Z as described hereinbefore with reference to Figure 1. If the integrator count is greater than or equal to the threshold Z then the system increments "the time above the sub-threshold W" and the "total time above the sub-threshold W" at steps 23 and 24. If the integrator count is not greater than or equal to the threshold Z at which a hard count is indicated, the integrator count is incremented at step 6 as hereinbefore described but there is a subsequent determination at step 20 as to whether the integrator count is greater than the sub-threshold W. If the count is greater, then the system increments the "time above the sub-threshold W" period and "total

time above the sub-threshold W" as indicated at steps 21 and 22 in a similar manner to that described hereinbefore in the case where no fault is detected in the system of Figure 4.

As illustrated in Figure 5, the system is capable of providing a signal indicative of the total time the sensor fault count exceeds the sub-threshold W and also the time of each period that the fault count exceeds the threshold. These values may be used to give an indication of the general trends in intermittent faults before they become registered as hard faults on reaching the threshold Z. These data trends may be established by analysing the time periods calculated by the method illustrated by Figure 5, in different ways. For instance, the maximum continuous period above the sub-threshold W may be used, or the total time above this threshold. It is also possible to monitor the frequency of periods above the sub-threshold. An advantage of the embodiment described in Figure 5 is that the system provides an output indicative of the state of the system being sensed, while reducing the requirement for transferring an excessive quantity of data to be processed. The data trends determined may be correlated against the total flight time of an aircraft or with individual flight phases such as take-off or landing or flight events such as deployment of undercarriage, or other maintenance messages which may be received from health monitoring systems.

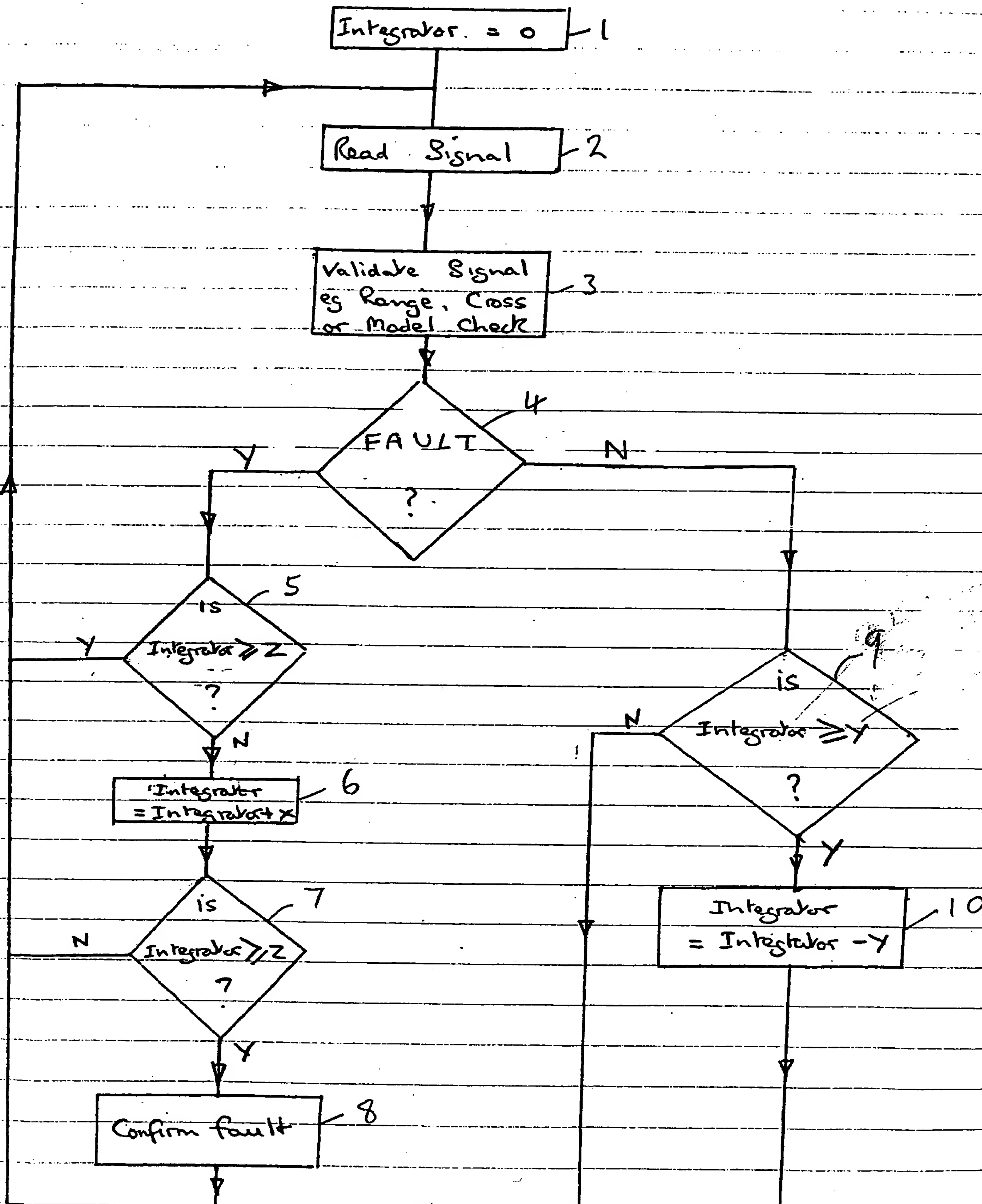
Integrator = 0
1
Read Signal
2
Validate Signal eg Range, Cross or Model check
3
FAULT ?
4
Y
N
is Integrator ≥ Z ?
5
Y
N
Integrator = Integrator + X
6
is Integrator ≥ Z ?
7
N
Y
Confirm fault
8
is Integrator ≥ Y ?
9
N
Y
Integrator = Integrator − Y
10

FIG 1

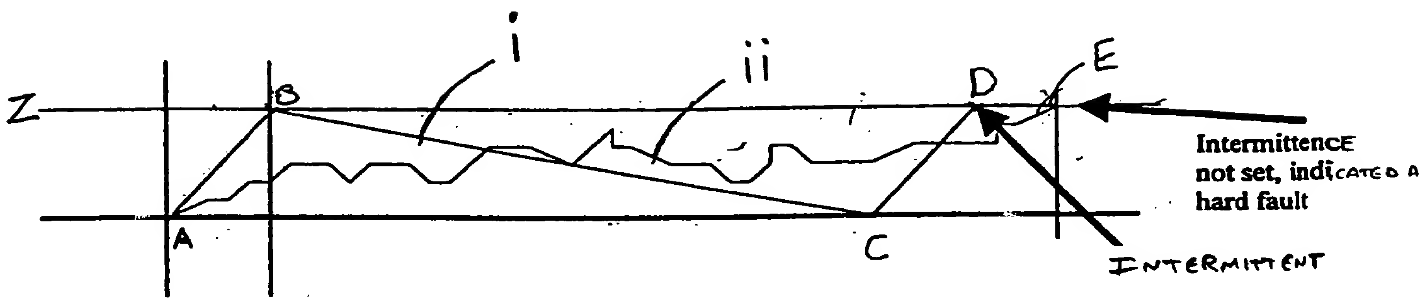
i
ii
Z
B
D
E
A
C
Intermittence not set, indicated a hard fault
INTERMITTENT

Fig 2a

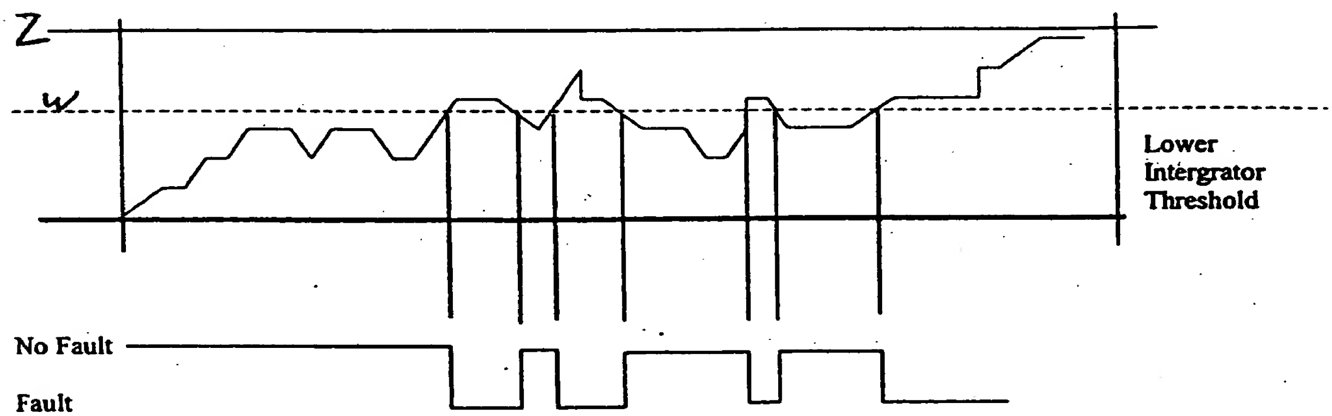
Z
w
Lower Intergrator Threshold
No Fault
Fault

Fig 5

**Classic Hard Fault (Hard Fault Message)**

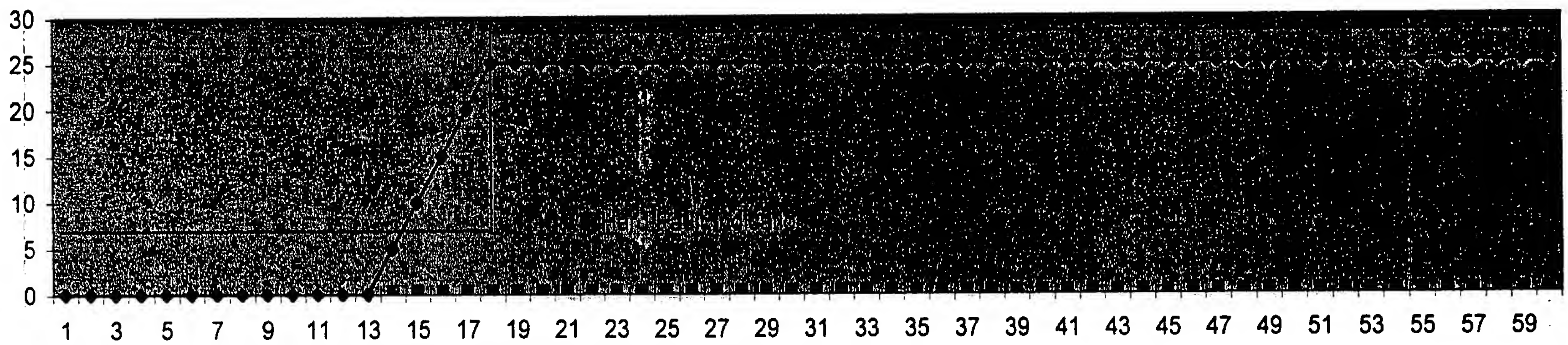


Fig 2b

**Periodically Intermittent - Long Term Fail Rate < Up/Down ratio (No Message)**

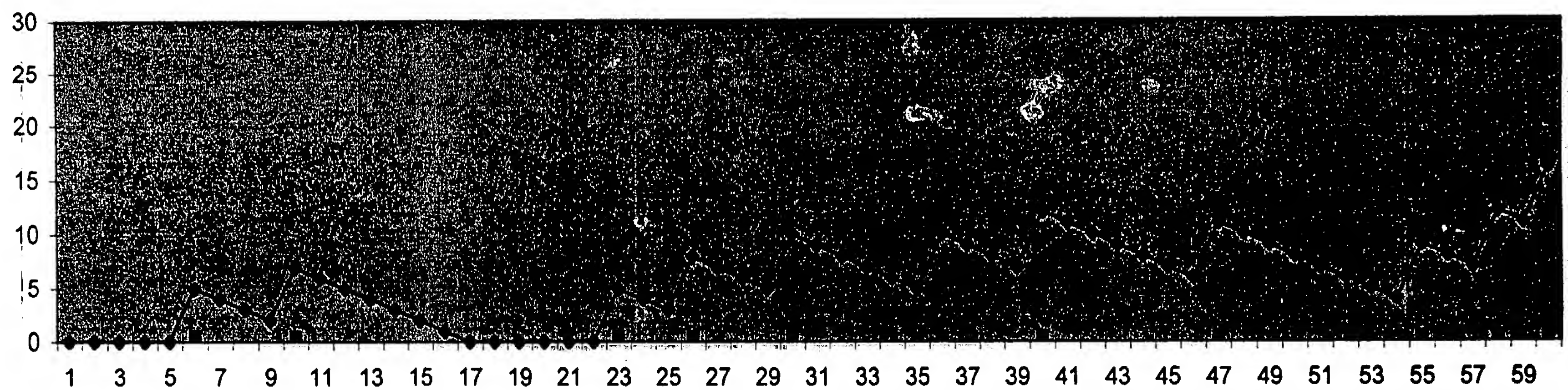


Fig 2c

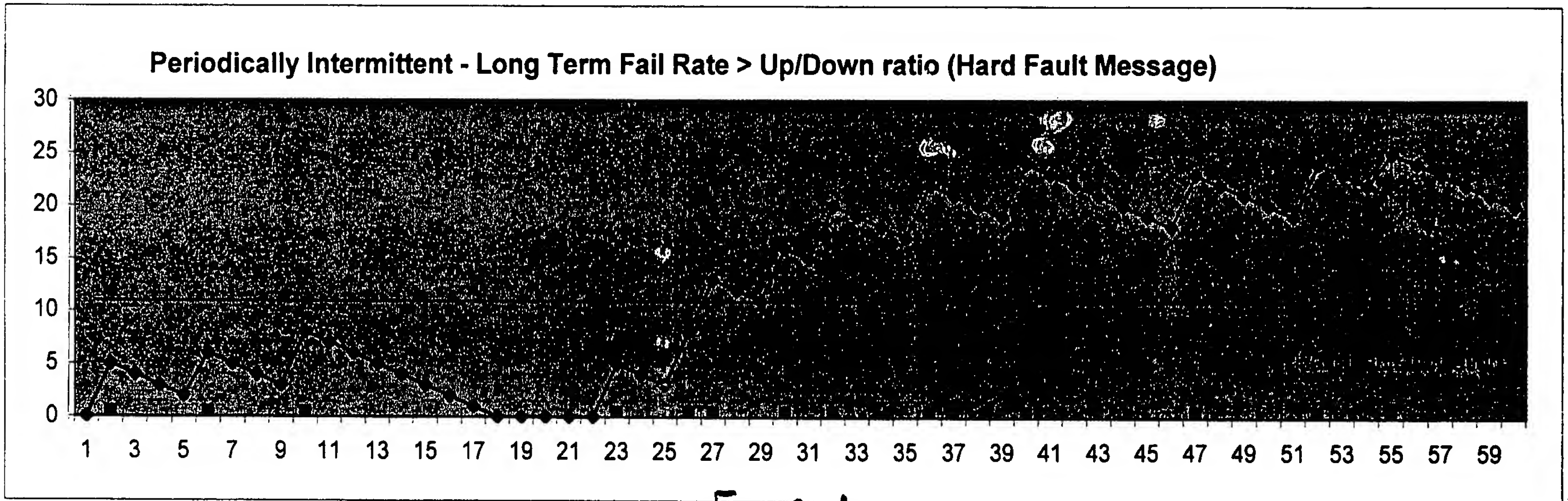
Periodically Intermittent - Long Term Fail Rate > Up/Down ratio (Hard Fault Message)
30 25 20 15 10 5 0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59

Fig 2d

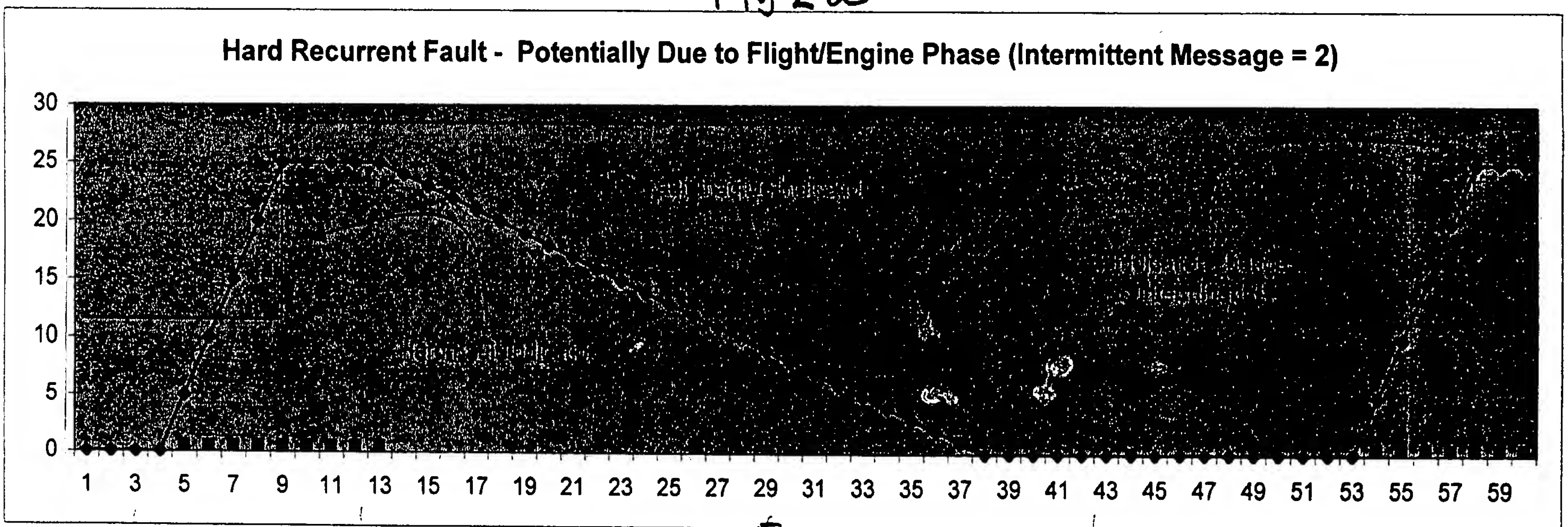
Hard Recurrent Fault - Potentially Due to Flight/Engine Phase (Intermittent Message = 2)
30 25 20 15 10 5 0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59

Fig 2e

Integrator With ratio monitor



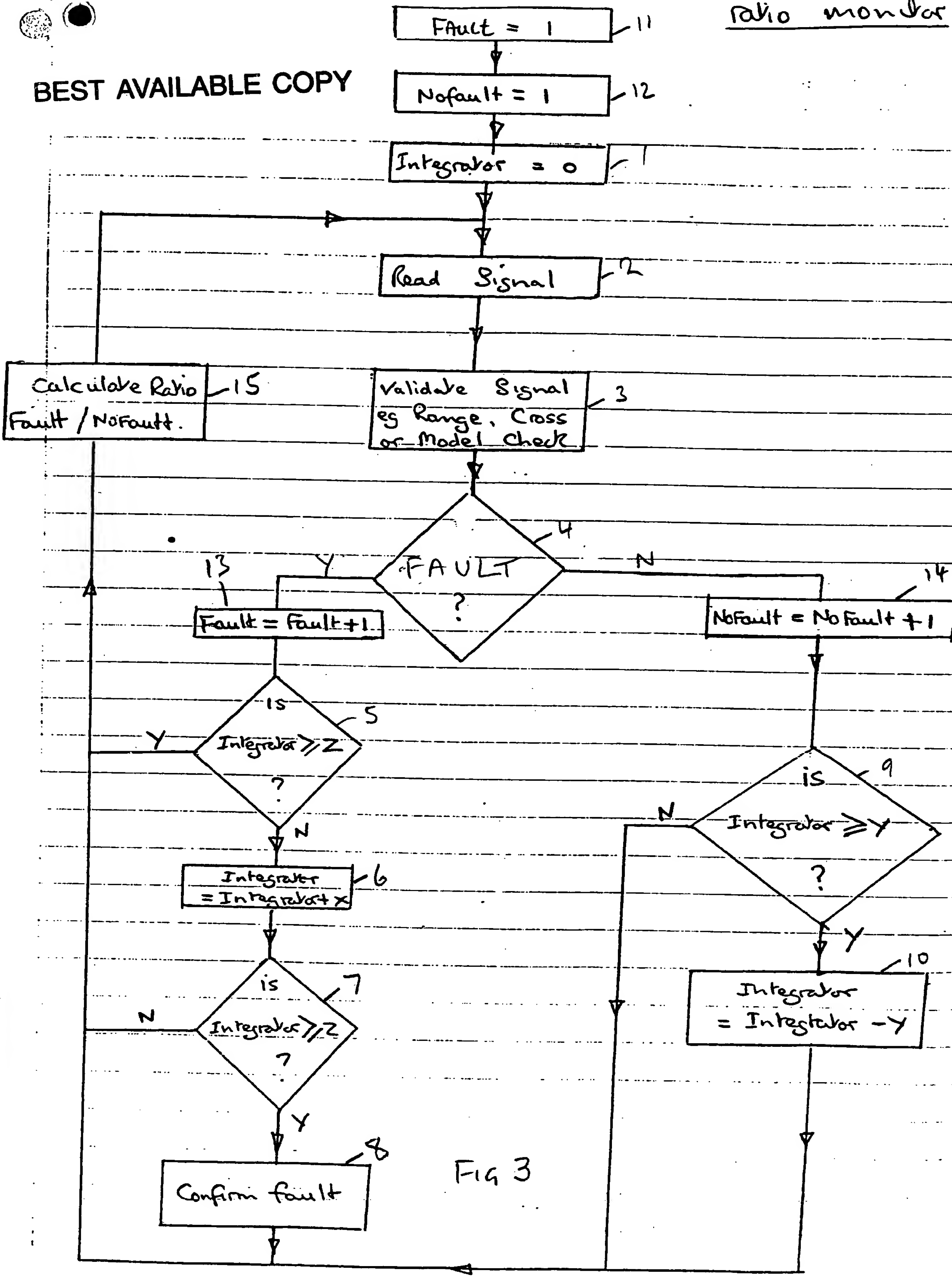


FIG 3

Additional lower Threshold



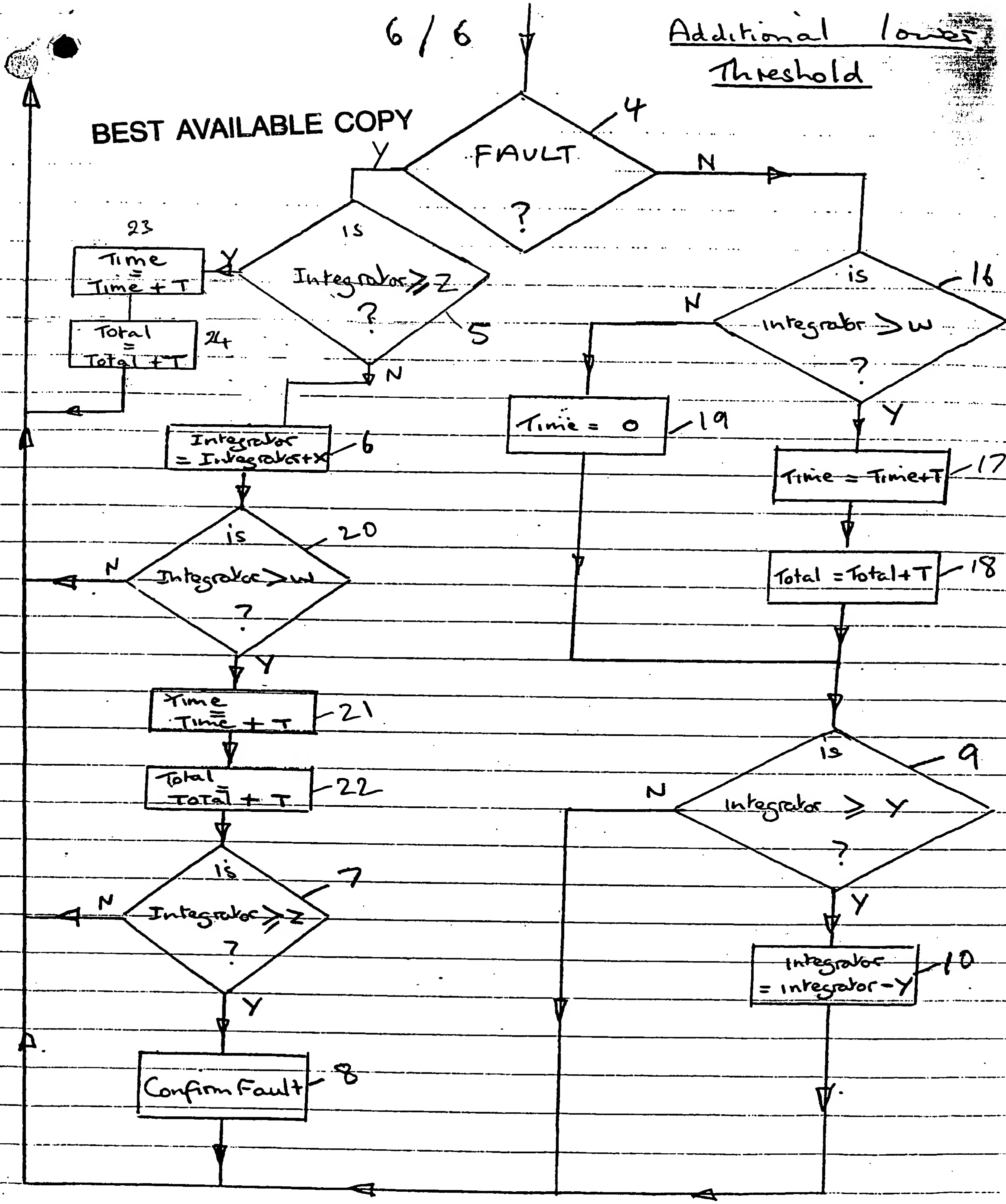


Fig 4